Longitudinal emittance measurement using particle detectors

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Abstract

Having insight to the full 6-dimensional phase space configuration of the beam marks the optimal case. At low energy plenty of well established methods are available to monitor the transversal phase space on all intensity scales. In the following an interceptive device to access the longitudinal phase space via Time-of-flight (TOF) is presented which is currently under development at GSI UNILAC. The working principle of the device is based on single particle detection within a drift length between two detector modules with the UNILAC radio frequency serving as spatial reference timing.

WORKING PRINCIPLE

The presented method relies on coincidence measurements at two detector sections. Therefore the primary beam is attenuated in two stages to achieve low entrance currents and thus very low count rates. The final attenuation stage is provided by a Ta foil (120 µg cm\(^{-2}\)). Particles hitting the Ta foil undergo coulomb scattering and are selected by two collimators at a laboratory angle of 2.5° with a solid angle of 10\(^{-4}\). Subsequently all beam particles that have passed the collimator setup traverse a drift distance between a MCP-foil compound module and a diamond detector of 80 cm (see Fig. 2). Further details are given in [1] and [2].

The MCP is installed behind a thin Al foil (9 µg cm\(^{-2}\)) with a voltage difference of 2 kV applied to the foil with respect to the MCP front. Once a beam particle passes the Al foil released secondary electrons are accelerated towards the MCP.

Signals from MCP anode and diamond detector are processed by double threshold discriminators to reduce the walk induced by the range of MCP pulses from 100 mV up to 1.5 V [3]. To account for the phase information, the UNILAC RF is recorded as well as the macro pulse start timing. The TDC (CAEN Vx1290) provides a resolution of 35 ps (rms) with 25 ps LSB.

Depending on the charge state an entrance current of \(I_{\text{max micro}} \approx 25 \mu A\) is considered to be safe in terms of not melting the Ta foil. Therefore primary beam attenuation is achieved by quadrupole defocusing in front of the RFQ structures in case of low current measurements (see Fig. 1 for location details). High current measurements in contrast require the use of a different charge state after the gas stripper that precedes the device.

CONSTRUCTING THE PHASE SPACE

With the recorded detector events and UNILAC RF reference we are able to construct the longitudinal phase space by filling appropriate histograms. For now the relative energy deviation is received by linear approximation. Assuming that \(\Delta E \ll E\) and \(\Delta t = t_{\text{Dia}} - t_{\text{MCP}}\) the relative energy deviation writes as

\[
\frac{\Delta E}{\langle E \rangle} \approx \frac{dE}{E} \bigg|_{t=t_{\langle E \rangle}} = -2 \frac{dt}{t} \bigg|_{t=t_{\langle E \rangle}} \approx -2 \frac{\Delta t}{t_{\langle E \rangle}}, \tag{1}
\]

with \(\langle E \rangle = E(t_{\langle E \rangle})\), i.e. \(t_{\langle E \rangle}\) marks the traversal time of a particle of mean energy \(\langle E \rangle\). Using the diamond events with respect to UNILAC RF \(t_{\text{Dia}} - t_{\text{RF}}\) the longitudinal spatial information is extracted. To account for relative cable offsets and latency effects at the MCP module, the design energy of 1.4 MeV is used a priori, i.e.
data evaluation is based on central moments.

Figure 3: Zero current data recorded with different phase settings at IH2. Left plot 204°, right plot 219°. Corresponding emittance (rms) values and Twiss parameters are given in Tab. 1.

**EXPERIMENTAL DATA**

Low current measurements for different phase settings at IH2 are depicted in Fig. 3. General sensitivity to the longitudinal phase space configuration is expressed in the corresponding emittance (rms) values and Twiss parameters (see Tab. 1). It should be noted that the size of emittance values reflect the sensitivity of the longitudinal phase space with respect to the IH phase which is expected. Recent high current measurements within the HIPPI ’08 campaign are shown in Fig. 4.

<table>
<thead>
<tr>
<th>Phase Setting</th>
<th>( \varepsilon_{\text{rms}} ) [keV · ns]</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 3 204°</td>
<td>139</td>
<td>0.03</td>
<td>5.8</td>
<td>0.12</td>
</tr>
<tr>
<td>Fig. 3 214°</td>
<td>364</td>
<td>0.1</td>
<td>12.4</td>
<td>0.05</td>
</tr>
</tbody>
</table>

However, compared to theoretical models correlation values are too small, whereas the energy width is too big by almost a factor of two in case for an optimized beam. In this case beam parameters are expected to have an energy width of around 1\%\langle E \rangle but recorded data represents the beam with a lower limit of energy width of around 2\%\langle E \rangle. Considering the high timing and precision requirements this stands to reason that the energy resolution achieved is not sufficient.

Unsatisfying signal shapes from the MCP module are regarded as large contributions to the energy broadening. Additionally it is not clear if the indirect method of secondary electrons emission can be treated as constant time offset in good approximation, depending on the unknown energy spectrum of the released electrons. Calculations concerning straggling effects inside the Ta foil showed broadening of 0.12\%\langle E \rangle at maximum [1]. With an expected energy width of 1\%\langle E \rangle, this is sufficiently low. Current plans are to extend the drift space in order to enhance the energy resolution.

**REFERENCES**

